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Precipitation and Streamflow in the Black Hills

by

Howard K. Orr

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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PRECIPITATION AND STREAMFLOW IN THE BLACK HILLS

by

Howard K. Orr, Research Forester
Rocky Mountain Forest and Range Experiment Station

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PRECIPITATION AND STREAMFLOW IN THE BLACK HILLS

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INTRODUCTION

Precipitation has been measured in the Black Hills since early settlement. A fully equipped weather station was set up in Deadwood in 1877, the year after the town was platted on the site of the first gold placer claims in that area. Since then precipitation has been measured at scattered locations throughout the Black Hills and adjacent area.

The first streamflow records were published in 1903 (6). Measurements of six major streams were reported. Streamflow has since been recorded on nearly all the major streams in the Black Hills area, but most measurements cover periods of only a few years.

Precipitation records are more numerous, more continuous, and cover longer periods than streamflow records. In some drainages both precipitation and streamflow data are fragmentary. This report consolidates and interprets those records considered pertinent to a better understanding of precipitation and streamflow in the Black Hills area.

SOURCE MATERIAL

The best general account of Black Hills weather was written by Johnson (4). Weather factors dealt with include precipitation, temperature, evaporation, and wind. No streamflow information is given except a descriptive account of the major floods in the Black Hills area.

An intensive study of a number of Black Hills streams was made by Brown (1) in 1942. The main objective of this study was to evaluate the feasibility of bringing surface waterflow across the "zone of water loss" where streams cross the tilted and porous limestone and sandstone formations along the eastern side of the Black Hills. The report makes little reference to precipitation-streamflow relationships.

A large volume of precipitation data is available from U. S. Weather Bureau records. Monthly and annual precipitation at individual stations are summarized in the following available Weather Bureau publications: Bulletin W for the period from start of record through 1930; Bulletin W supplement for the period 1931 through 1952; and Annual Climatological Summaries for 1953 to date.

Streamflow records have been collected mostly by the U. S. Geological Survey. Each year's data are published in the Geological Survey "Water Supply Paper" series for the streams of the Upper Missouri Basin.

Additional precipitation data may be found in records collected during the summer by the U. S. Forest Service at fire lookouts. These records are often fragmentary and incomplete because the time at which lookouts are manned varies from year to year, depending on current weather conditions and fire hazard.

Streamflow data are generally inadequate to precisely establish streamflow characteristics and water-yield trends in relation to precipitation. Most records are too short. Flow in some streams was measured for special studies requiring only a few years' record and gaging stations were then abandoned. A number of gages were established within the past 10 years and most of these are still operating. Records from these gages are useful for some purposes, but they do not fulfill the need for detailed streamflow analyses. Most of the gages are located below the zone of water loss, and hence do not measure true water yield. Determination of water yield is also complicated by upstream water diversions which, in some cases, were not measured precisely and in others not measured at all. Reservoir construction has altered the pattern of seasonal flow in several major streams, making establishment of direct precipitation-streamflow relationships difficult if not impossible.

The 28-year record (1915-42) for Rapid Creek above Big Bend is the longest continuous record for any Black Hills stream. This record was compiled by Brown (1). The gaging station was located above the zone of water loss, and flow was not complicated by major water diversions or impoundments. Although weak in some places this record is the one most suitable for analysis of streamflow-precipitation relationships.

PHYSIOGRAPHIC AND GEOLOGIC FEATURES

The Black Hills is an isolated mountain area in the Northern Great Plains physiographic province. Because of location, size, and prominence the Black Hills area has been cited as an excellent example of increasing precipitation with elevation in an inland area (2). Total area is about 5,150 square miles, including the Bear Lodge Mountains in northeastern Wyoming. Elevation ranges from about 3,200 to 7,242 feet above mean sea level.

Exposed granites and metamorphic rock formations in the interior Black Hills are relatively impermeable to water. These formations, together called the "central crystalline" area, occupy approximately 20 percent of the total Black Hills area.

Ridges of limestone, sandstone, shale, and conglomerate formations form concentric circles around the central crystalline area. Surface waterflow diminishes or entirely disappears where channels cross these sedimentary formations. Many streams that flow yearlong in the central crystalline area become intermittent toward the outer edge of the Black Hills.

The area is drained by a large number of relatively small streams (fig. 1). In the South Dakota portion of the area streams radiate from the main divide, which is along the crest of the Limestone Plateau just west of the central crystalline area. Streams heading in Wyoming radiate from the crystalline rock area that forms the crest of the Bear Lodge Mountains. Utilization of water from such a drainage pattern requires handling small amounts of water in many places.

A major portion of the water yield comes from those streams heading near the divide and flowing east across the central crystalline area (fig. 1). Some of the north-flowing streams, notably Spearfish Creek, carry considerable surface water. Although Spearfish Creek heads on porous limestone, the stream has cut

down through this formation over much of its length into less porous sedimentary or crystalline formations beneath. Most of the streams radiating south and west flow over sedimentary formations throughout their entire length. Flow in these streams is intermittent most of the time.

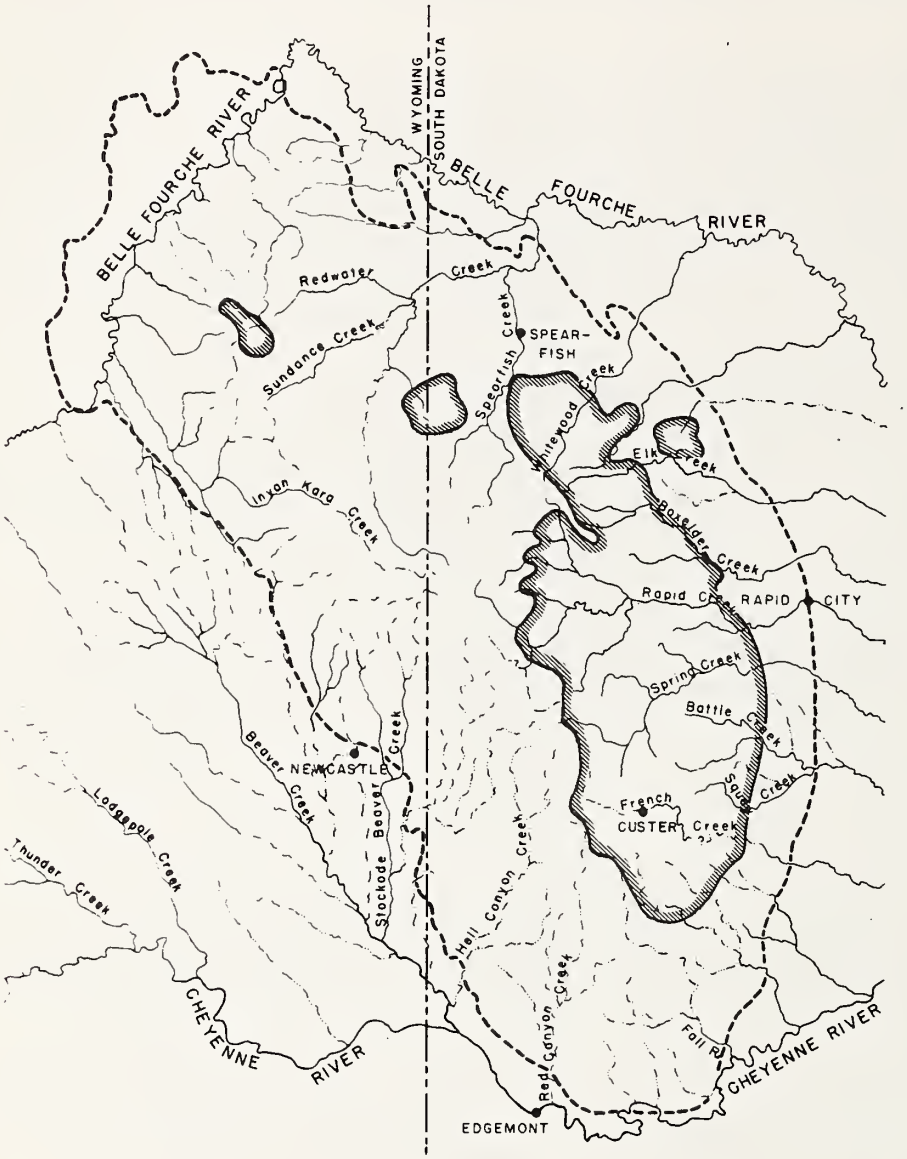

Figure 1.--Drainage map of the Black Hills and Bear Lodge Mountains. The heavy dashed line is along the sedimentary formation of the outer encircling ridge. The crosshatched lines encircle areas of metamorphic and igneous (crystalline) rock formations. Sedimentary formations are found in the remainder of the area.

The drainage pattern, geology, and soils of the Black Hills all appear to favor rapid concentration and drain out of ground water. The drainage pattern is relatively young. Streams in some places meander across meadows and parks, but over most of their length gradients are relatively steep and flow is swift. Streams flow in steep-walled canyons across the outer sedimentary formations. In much of the central crystalline area streams flow in well defined V-shaped valleys with steep side slopes. Slope and ridge soils are shallow, and there is little evidence of severely restricted drainage. Hence, ground water probably moves rapidly from the slopes and in the valley fill, which according to Brown (1) is coarse and no more than 10 to 15 feet thick in most places.

GENERAL CLIMATE

The climate of the Black Hills is similar in many respects to the continental type climate of the surrounding plains, except that it is modified by the prominence of the uplift itself. Precipitation is higher and temperatures are generally lower. Since water yield, in general, increases with precipitation and lower temperatures, the Black Hills yield more water than the adjacent plains.

Air temperatures are higher in or near the foothills than in the interior and higher Black Hills (table 1). Average growing season varies from a maximum of 154 days at Rapid City to a recorded minimum of 97 days at 6,192 feet elevation. Temperatures are also higher at comparable elevations in the southern than in the northern Black Hills, as shown by comparing Hot Springs and Spearfish (table 1). Since rate of moisture loss to evaporation and use by plants, in general, increases with temperature and length of growing season, higher temperatures would be expected to produce lower water yield in the foothills and southern Black Hills than in the northern and higher Black Hills.

VEGETATION

The more humid and cooler climate of the Black Hills uplift has produced a forest cover in sharp contrast to the grass cover of the surrounding plains. The forest cover is dominated by ponderosa pine (Pinus ponderosa) on all but the more moist sites, where white spruce (Picea glauca) grows often in nearly pure stands. Mixed with these two species are small amounts of

Table 1. --Average monthly and annual air temperature at selected stations in the Black Hills area

Location of station	Elevation	Years of record	Air temperature											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Ft.	No.	Degrees Fahrenheit												
South Dakota															
Custer	5,322	11	22.0	23.3	27.1	39.2	47.7	56.7	64.6	63.0	53.3	43.7	30.8	23.5	41.2
Hot Springs	3,535	47	25.1	27.8	34.3	46.8	56.8	66.3	75.3	73.2	62.9	51.0	36.9	29.0	48.8
Lead	5,245	48	24.3	25.7	29.7	41.4	51.1	60.2	69.7	67.9	58.4	48.0	34.4	28.1	44.9
Rapid City	3,165	69	21.1	23.9	31.3	44.5	54.7	63.7	72.3	70.9	60.5	49.1	35.3	25.7	46.1
Spearfish	3,685	59	25.4	25.8	33.5	45.1	54.4	63.4	71.1	69.2	60.3	49.4	36.8	27.5	46.8
Wyoming															
Newcastle	4,480	40	22.1	25.3	33.4	44.2	54.3	64.6	73.0	71.1	60.3	47.8	34.2	25.8	46.3

quaking aspen (Populus tremuloides) and paper birch (Betula papyrifera). Willows (Salix spp.), red osier dogwood (Cornus stolonifera), and water birch (Betula occidentalis) occur along many of the streams. Although forest cover characterizes the Black Hills in general, there are a number of open meadows, parks, and "prairies" ranging up to hundreds of acres in size. Here are found representatives of the true prairie, the plains, and Rocky Mountain floras.

Ponderosa pine occupies more than half of the combined Black Hills - Bear Lodge Mountain area. Dense second-growth stands are common. Because of its extent and density ponderosa pine appears to be the most important single plant species from the standpoint of moisture use and effects on water supply.

PRECIPITATION

Precipitation is of the plains type characterized by greatest amounts in the spring, decreasing through the summer, and small amounts, mainly snow, in the fall and winter months. General spring storms approach mostly from the southwest, while winter storms approach mostly from the west or northwest. Summer precipitation comes mostly from thunderstorms. Although high intensity rainfall and hail are common, individual storms of this type are usually confined to relatively small areas.

ANNUAL PRECIPITATION

Greatest annual precipitation occurs in the vicinity of Lead in the northern part of the Black Hills and in the Bear Lodge Mountains (fig. 2). Amounts decrease rapidly toward the plains, and gradually from north to south along the uplift. At comparable elevations precipitation is generally greater in the northern Black Hills than to the south. For example, Sturgis and Hot Springs at comparable elevations near the northeastern and southern edges of the area receive 19.71 and 17.61 inches annual precipitation, respectively.

The islands of relatively high precipitation north of Newcastle, east of Custer, and east and west of Hot Springs are apparently caused by localized sharp increases in elevation. The one north of Newcastle is in the vicinity of Sweetwater Mountain and Mount Pisgah. The island east of Custer includes much of the Harney Range which reaches a maximum elevation of 7,242 feet. The prominence of Battle Mountain apparently causes the island of increased precipitation northeast of Hot Springs.

Annual precipitation varies greatly between years. In a 70-year period of record at Rapid City, yearly precipitation has ranged from a maximum of 27.42 inches in 1946 to a minimum of 7.51 inches in 1936 (fig. 3)--a ratio of almost 4 to 1. The 5-year moving average in figure 3 shows definite wet and dry cycles within the period of record at Rapid City despite occasional extreme differences between successive years. The 1890's were relatively dry. Precipitation was then above average over most of the next 10-year period. The period 1910 through 1914 was droughty followed by a period of generally above-average precipitation to about 1929. The severe drought of the 1930's then followed. The 1940's were a period of near- or above-average precipitation. Since 1950, precipitation has fluctuated from considerably below to slightly above average, but the trend has been generally upward.

The same cyclic precipitation pattern appears characteristic throughout the Black Hills as shown by a check of records for stations ranging from the plains to the highest precipitation zone. Dry cycles are not consistently drier in relation to average precipitation at lower elevation stations than at higher stations nor are wet cycles consistently any wetter in relation to average precipitation.

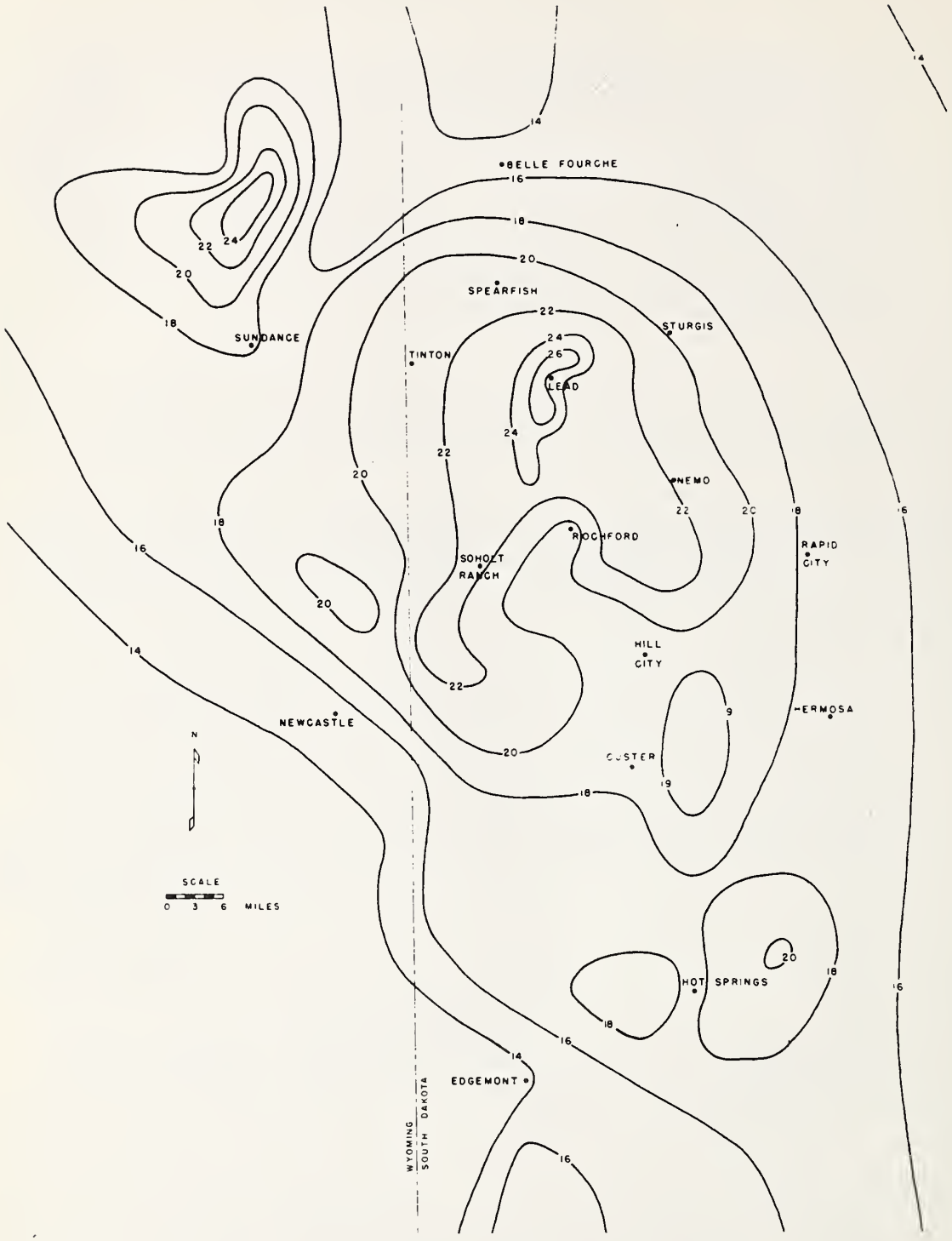

Figure 2. --Isohyetal map of average annual precipitation in the Black Hills area.

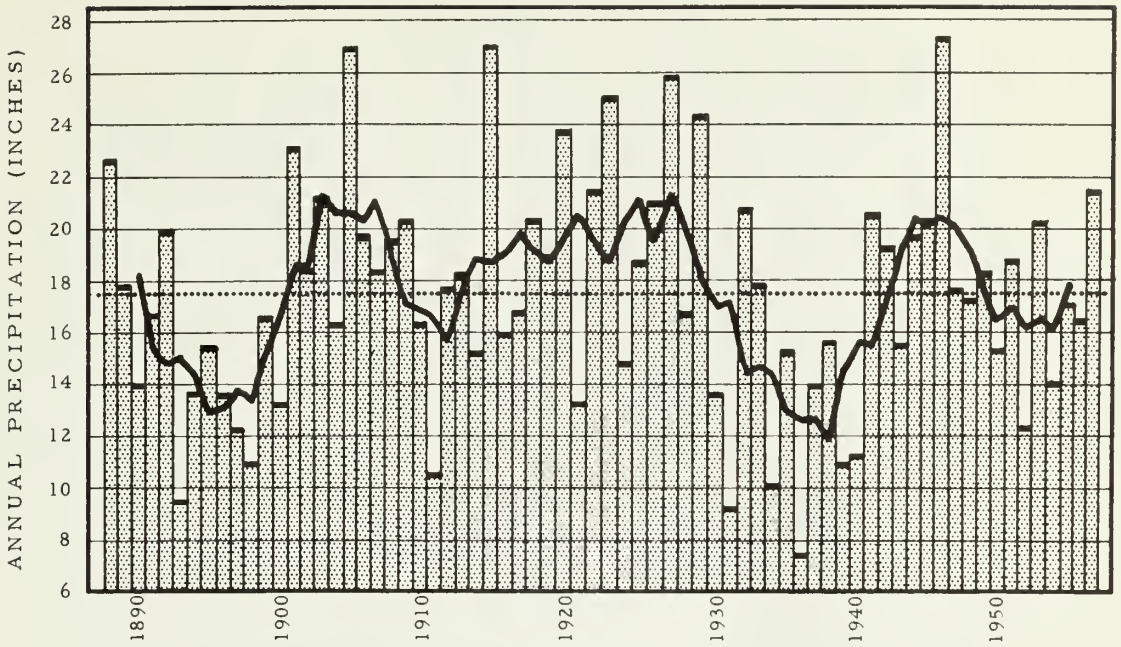

Figure 3. --Precipitation by years at Rapid City, South Dakota. The horizontal dotted line is average annual precipitation and the heavy solid line is the 5-year moving average plotted at midpoint.

SEASONAL DISTRIBUTION

Maximum precipitation falls in May or June. May is the maximum month for the southwestern and southern edge of the Black Hills. To the north along the uplift May and June precipitation becomes nearly equal. North of Rochford, in the Bear Lodge Mountains, and north and east of the Black Hills, June is the maximum precipitation month.

Precipitation gradually declines through the summer and fall to a minimum in February at most stations (see fig. 6, page 15). However, at numerous stations there is no more than a few hundredths of an inch difference in precipitation for November, December, January, and February. Precipitation then starts a gradual climb to the seasonal maximum in May or June.

Northern and higher parts of the Black Hills receive more precipitation both in summer and winter than southern parts (figs. 4 and 5). The difference is especially pronounced in

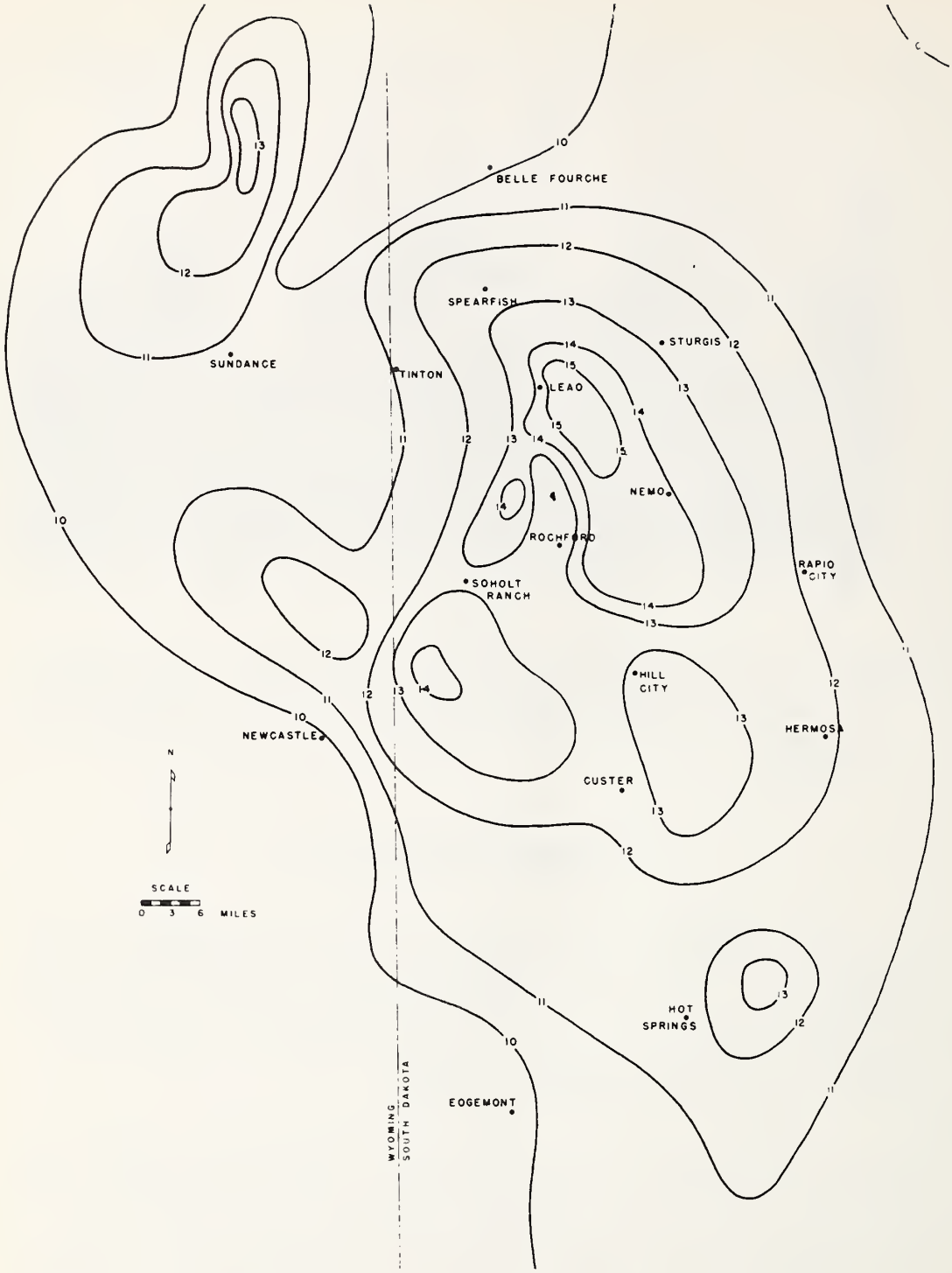

Figure 4. --Isohyetal map of summer precipitation in the Black Hills area (summer period considered May 1 - September 30).

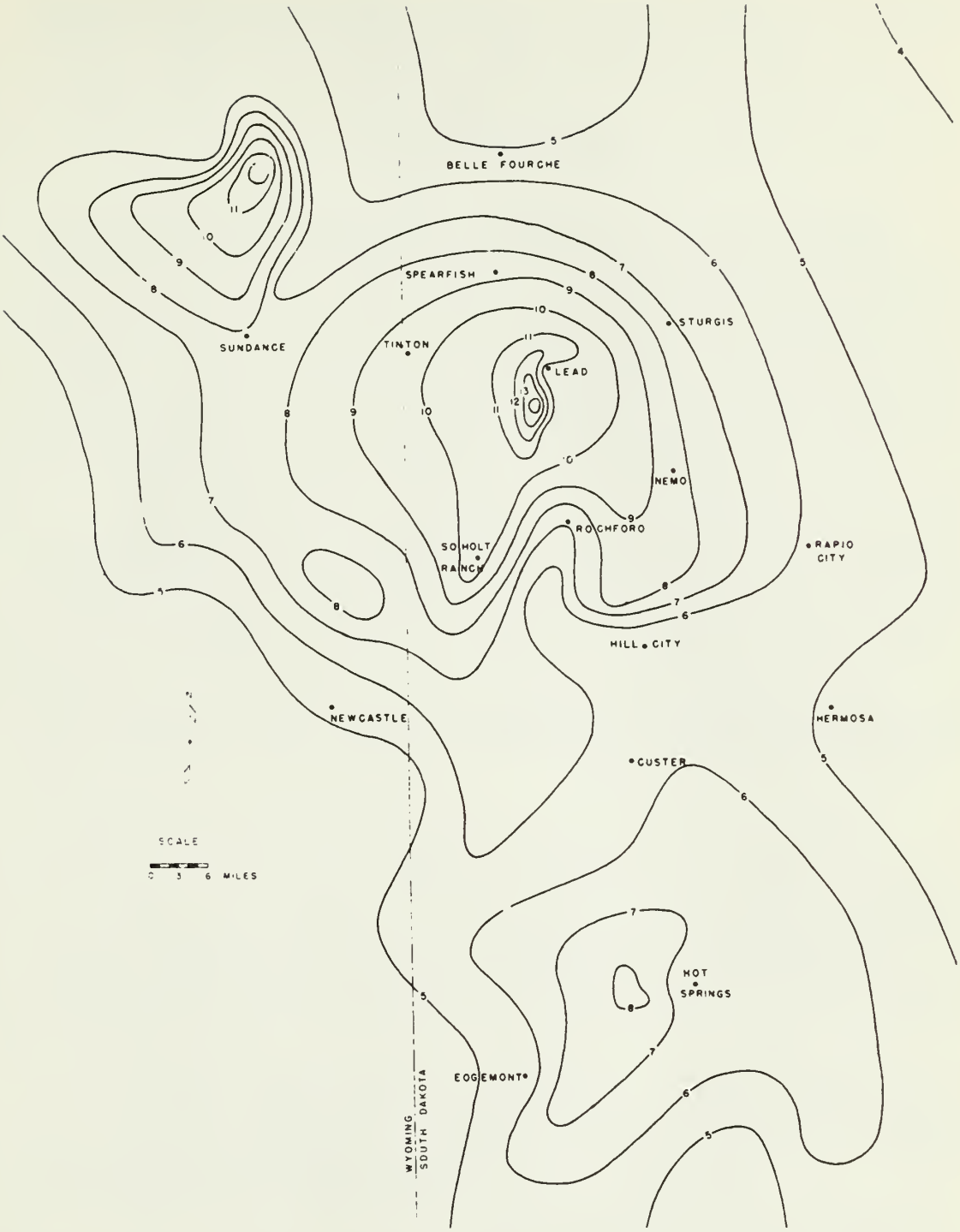

Figure 5. --Isohyetal map of winter precipitation in the Black Hills area (winter period considered October 1- April 30).

winter and is reflected by the snowpack that accumulates in parts of the northern Black Hills and along the Limestone Plateau, while very little snow accumulates in the southern Black Hills. Conversely, this southern part receives a higher percentage of total annual precipitation during the summer than the northern part--about 69 percent as compared with about 57 percent.

Some differences in amounts and seasonal distribution of precipitation between southern and northern parts of the Black Hills are traceable to different types of storms and the directions from which the storms approach. The heavy spring snows or rains come mostly from so-called Colorado-type storms. They approach from the southwest, with centers usually passing just south and to the east of the Black Hills (4). These storms are the chief source of precipitation that falls during the growing season in the southern half and particularly in the southeastern part of the Black Hills. These storms are most numerous in May, the month of maximum precipitation in about the southern half of the area. Circulation of air in these storms draws warm moist air up from the south and upon approaching the Black Hills uplift creates conditions especially favoring precipitation.

Summer storms are nearly all of the thunderstorm type (4), and although they occur frequently, individual storms usually cover relatively small areas.

The more general and widespread winter storms are of the Northern Rocky Mountain or North Pacific types (4). Northern Rocky Mountain type storms approaching from the west are often deflected, with centers passing either directly over or to the south of the Black Hills. These storms are nearly always more severe in the extreme southern Black Hills than in the central part of the area. Storms of the North Pacific type, approaching from the northwest, usually pass over the north end or to the north of the Black Hills. The greatest increase in precipitation with elevation occurs in winter months and in those northern parts of the area most directly in the line of approach of these North Pacific storms (fig. 5). They apparently are the main source of the relatively heavy winter precipitation and snowpack buildup in the northern Black Hills.

Precipitation from the general winter and spring storms is thus lacking in the south central and southwestern Black Hills. A larger than average proportion of total annual precipitation in this area is received from summer thunderstorms. Some

stations in the area have recorded an average of nearly 75 percent of total annual precipitation during the growing season.

STREAMFLOW

Quantity of streamflow is here expressed in terms of area inches of runoff over an entire drainage. By strict definition, runoff is that portion of the total surficial outflow from a given drainage area that has its origin in precipitation on that area (5). Since there are places in the Black Hills where water is diverted from one drainage area to another and springs materially contribute to flow in others, runoff and surficial flow are not synonymous in most streams. However, for those periods and in those watersheds for which specific data are quoted, the two are essentially the same.

Most of the existing records of runoff in Black Hills streams are not suitable to establish average flow or water-yield characteristics. As previously mentioned records are of too short duration, gages are located downstream from the zone of water loss, or the record is complicated by upstream water diversion or impoundment. The longest and otherwise most suitable record for detailed analysis is the one for Rapid Creek above Big Bend for the period 1915 through 1942. Therefore analyses of specific water yield and streamflow characteristics are based primarily on this record.

WATER YIELD

Runoff averaged 3.06 inches per year from the upper 332 square miles of Rapid Creek above Big Bend between 1915 and 1942. This was 14 percent of annual precipitation in the watershed, which averaged 21.46 inches.

Table 2 shows runoff in six other east-flowing streams for the year 1946. This is the only complete concurrent year of record for all these streams from above the zone of water loss. There is no comparable Rapid Creek record for this period.

Average annual water yields from the six streams listed in table 2 are probably considerably lower than in 1946, the maximum precipitation year in most of the Black Hills area (see fig. 3, page 10). Assuming that 37.28 inches is a reasonable average of precipitation over the entire Elk Creek watershed, the water yield was 26 percent. Water yield from French Creek was about 6 percent of the 24.28 inches

Table 2. --Runoff in six watersheds draining east out of the Black Hills, 1946

Drainage	Area	Runoff	Precipitation
	Square miles	Inches	Inches
Elk Creek	21	9.81	37.28
Boxelder Creek	96	5.21	North to south
Battle Creek	66	3.43	
Squaw Creek	25	3.28	
Spring Creek	159	3.19	
French Creek	98	1.54	24.28

of precipitation that fell at Custer during the year. There are no precipitation data suitable for calculation of yield from the other four streams, but the normal precipitation pattern indicates that the yields were probably intermediate.

Water yield from the Black Hills is low compared with western mountain areas, which receive the greater portion of annual precipitation during the winter in the form of snow. Water yield from a small watershed near the Continental Divide in north central Colorado averaged about 11 inches per year from 1943 through 1950 or about 37 percent of the 30 inches average annual precipitation (3). This high mountain area receives 75 percent of total annual precipitation in the form of snow between October and June, when evaporation and transpiration rates are low. The 30 inches annual precipitation is higher than the average of any Black Hills station. But it is lower than the 37.28 inches that fell in the head of Elk Creek in 1946, when water yield was 9.81 inches or 26 percent of precipitation.

Water yield in the Black Hills is strongly influenced by the seasonal distribution of precipitation. Average monthly runoff and precipitation in the Rapid Creek watershed above Big Bend are shown in figure 6. In March, both start to climb from their winter low and rise steadily; runoff, to a maximum in May; precipitation, to maximum in June. By June the growing season is well underway and evaporation and moisture use by plants

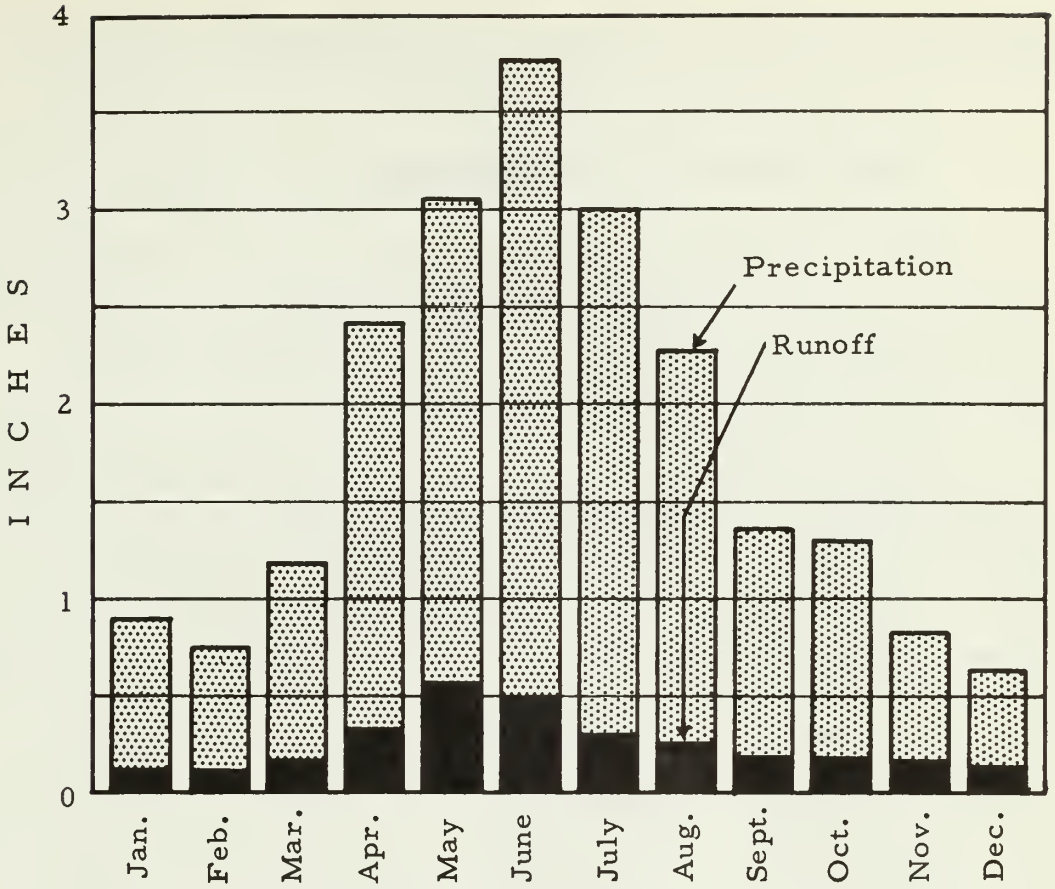

Figure 6. --Average monthly precipitation and runoff from the Rapid Creek watershed for the period 1915-42.

have increased to near maximum rates for the year. Most of the precipitation in June and the remainder of the growing season apparently goes into soil storage and is used by plants or lost to evaporation. It appears to make little contribution to runoff except in years when exceptionally large heavy storms occur. Declining precipitation during the remainder of the year is seldom more than enough to satisfy the storage requirements of the dry soil and therefore also makes little direct contribution to runoff.

Precipitation-streamflow data for 1920 and 1927 further illustrate the effect of precipitation pattern. Water yield in August 1927 was less than half the yield in May of that year, although August precipitation was 1 inch more than the amount received in May. In July and August 1927 precipitation totaled 8.09 inches and runoff was 1.20 inches. In April and May 1920

precipitation totaled 7.39 inches, 0.70 inch less than in July and August 1927, but runoff was 4.07 inches, 2.87 inches more.

VARIATION WITH GEOGRAPHICAL LOCATION

There are marked differences in water yield with geographic location. This is plain in table 2 (page 14) which shows water yield decreasing from Elk Creek on the north to French Creek on the south. Flow is intermittent in most of the streams south and west of French Creek (see fig. 1, page 4).

Greater water yield from northern than southern parts of the Black Hills is due mainly to higher precipitation (see fig. 2, page 8). However, it is also believed partially due to lower temperatures (see table 1, page 6). Evaporation stress and transpiration by plants, collectively called evapo-transpiration, in general decrease as temperature decreases. By the use of equations developed by Thornthwaite (7) in which air temperatures and day length are the main factors, inches of water needed to satisfy evapo-transpiration demands can be calculated. The calculated evapo-transpiration demand at Lead is 2.65 inches of water in May, 4.06 inches in June, and 5.12 inches in July. Precipitation is 3.93 inches, 3.87 inches, and 2.52 inches for these 3 months, respectively. At Hot Springs, where temperatures are higher, calculated evapo-transpiration demand is 3.04 inches of water in May, 4.60 inches in June, and 5.86 inches in July. Here precipitation is 3.10, 3.01, and 2.20 inches in May, June, and July, respectively.

Precipitation must exceed evapo-transpiration demands and bring the soil to maximum moisture-holding content before water will percolate to ground water and streamflow. Hence, May precipitation contributes materially to streamflow in the Lead vicinity, while in the Hot Springs area it probably makes little or no contribution. Little runoff is believed to be yielded from June or July precipitation in either place. Calculated evapo-transpiration demand exceeds precipitation throughout the remainder of the summer to September at Lead and to October at Hot Springs. By this time of year precipitation is low but evapo-transpiration demands are also low because of lowering temperatures. Precipitation exceeds evapo-transpiration demand throughout the winter months to the following April. The surplus moisture during this period appears more than adequate to replenish soil moisture in the Lead vicinity in most years. But water surplus

in the Hot Springs vicinity is rarely more than enough to replenish soil moisture. Aside from differences in precipitation this helps explain why flow is intermittent in most southern Black Hills streams in contrast to perennial flow in streams that head in northern parts of the area.

VARIATION WITH YEARS

The 1915-42 Rapid Creek data are again the best available to illustrate year-to-year variations in runoff. Although water yield averaged 3.06 inches per year there were wide fluctuations in the period (fig. 7). Greatest annual runoff was 8.04 inches in 1920 and the least was 0.51 inch in 1940 (fig. 8)--a ratio of 15.8 to 1.

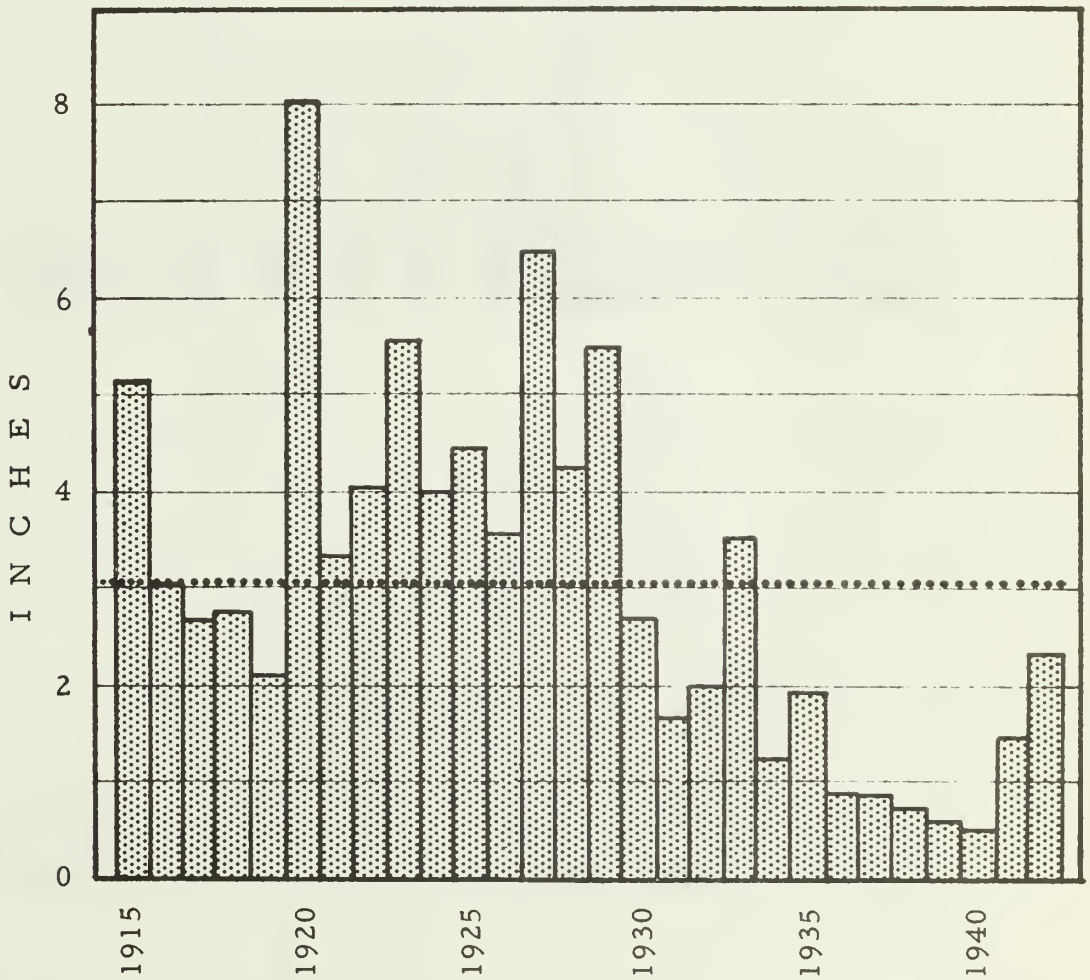

Figure 7. --Yearly runoff from Rapid Creek above Big Bend for the period 1915 through 1942. The dotted line represents average yearly runoff for the period.

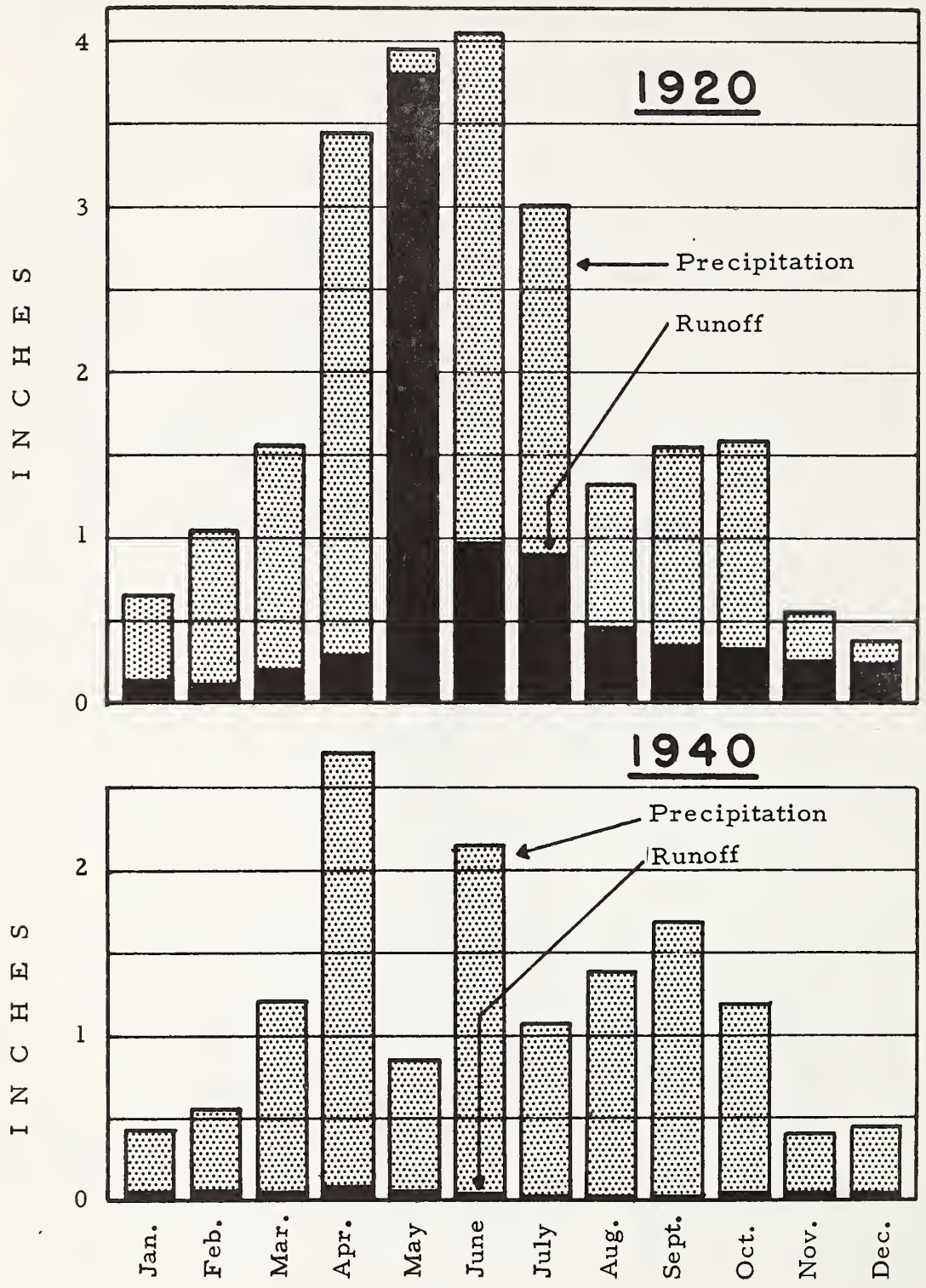

Figure 8. --Monthly precipitation and runoff from the Rapid Creek watershed in 1920 and 1940, the years of maximum and minimum water yield in the period 1915-42.

The large amount of runoff in May 1920 was apparently due to an unusually heavy accumulation of snow in April and heavy rainfall concentrated within a short period in early May. This produced one of the most devastating floods ever recorded on Rapid Creek. Streams in the southern Black Hills also flooded during this period. Rapid Creek flow continued above normal the remainder of the year, but receded in a nearly normal pattern from August on.

The second largest yearly runoff was 6.51 inches in 1927 (fig. 9). This was also a near-maximum precipitation year. The runoff pattern by months was similar to the long-term average (see fig. 6, page 15) except for a slight rise in August due to nearly twice average precipitation.

RUNOFF-PRECIPITATION RELATIONSHIPS AND TRENDS

May precipitation makes a greater direct contribution to runoff in Rapid Creek than any other month. The coefficient for correlation of May precipitation with total calendar year runoff was 0.599 (significant at the 1-percent level). Precipitation at Rochford was used in this analysis since it was found to be a better index of runoff in Rapid Creek than the average of three precipitation stations in the area.

Precipitation in the remaining months of the year makes a minor but nevertheless significant contribution to runoff. When total annual precipitation was related to total annual runoff, the correlation coefficient was 0.713 (significant at the 1-percent level). Total annual precipitation accounts for 51 percent of the variation in annual runoff; May precipitation alone accounts for 36 percent.

Current-year runoff in Rapid Creek is also directly related to precipitation in the preceding September-December period. Inclusion of this antecedent precipitation factor with current-year precipitation raised coefficient for correlation of runoff with precipitation from 0.713 to 0.835. Antecedent fall precipitation accounts for an additional 19 percent of the variation in current year runoff.

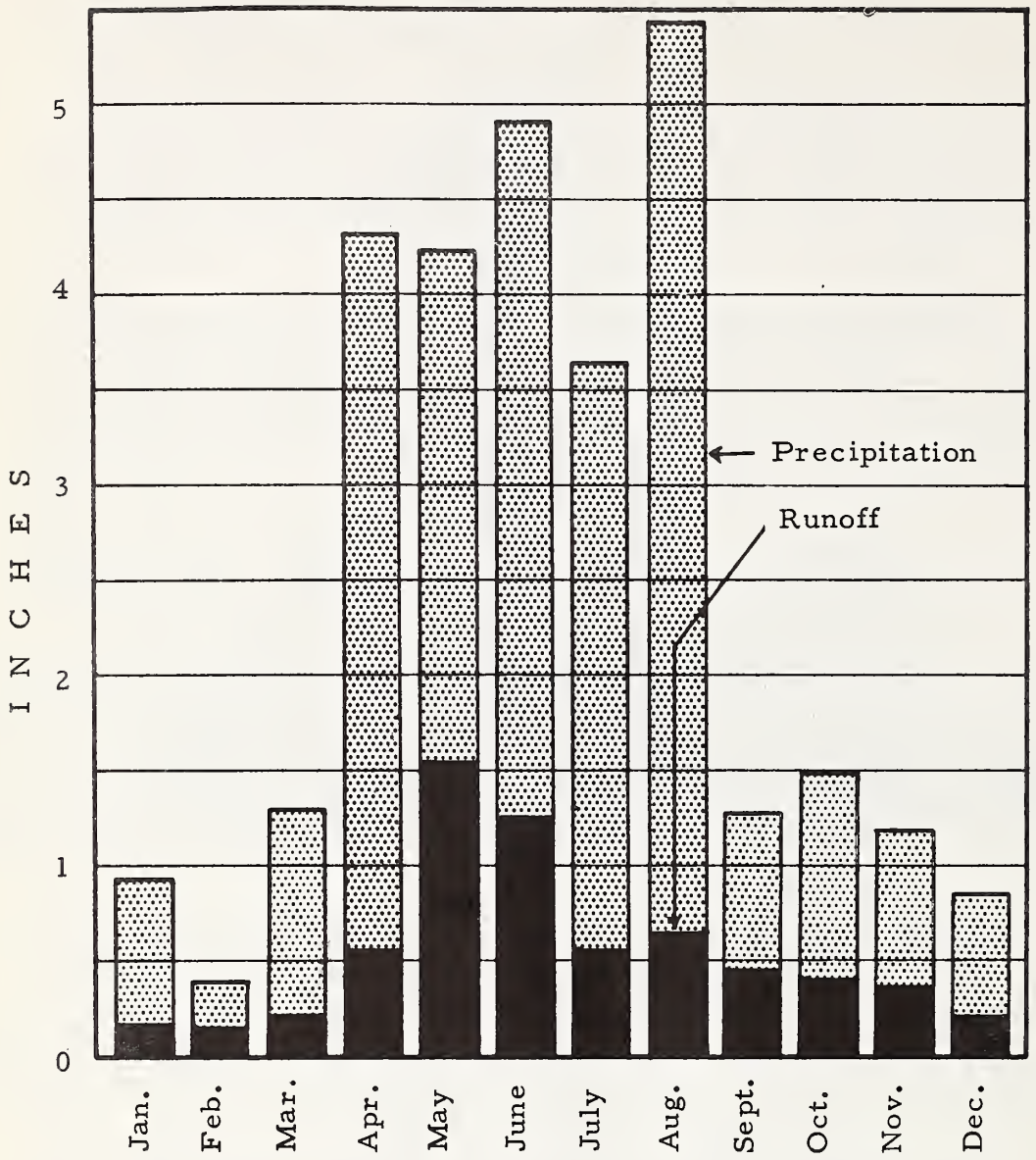

Figure 9. --Monthly precipitation and runoff from the Rapid Creek watershed in 1927, the year of second greatest water yield in the period 1915-42.

Figure 10 shows the net relationship of annual runoff to annual precipitation for the period 1915-42, with antecedent precipitation held at its average (mean) value of 4.06 inches. The relationship has the equation:

$$\hat{Y} = 0.2042 X_1 - 1.0831$$

where $\hat{Y}$ = estimated runoff in inches

X_1 = annual precipitation in inches

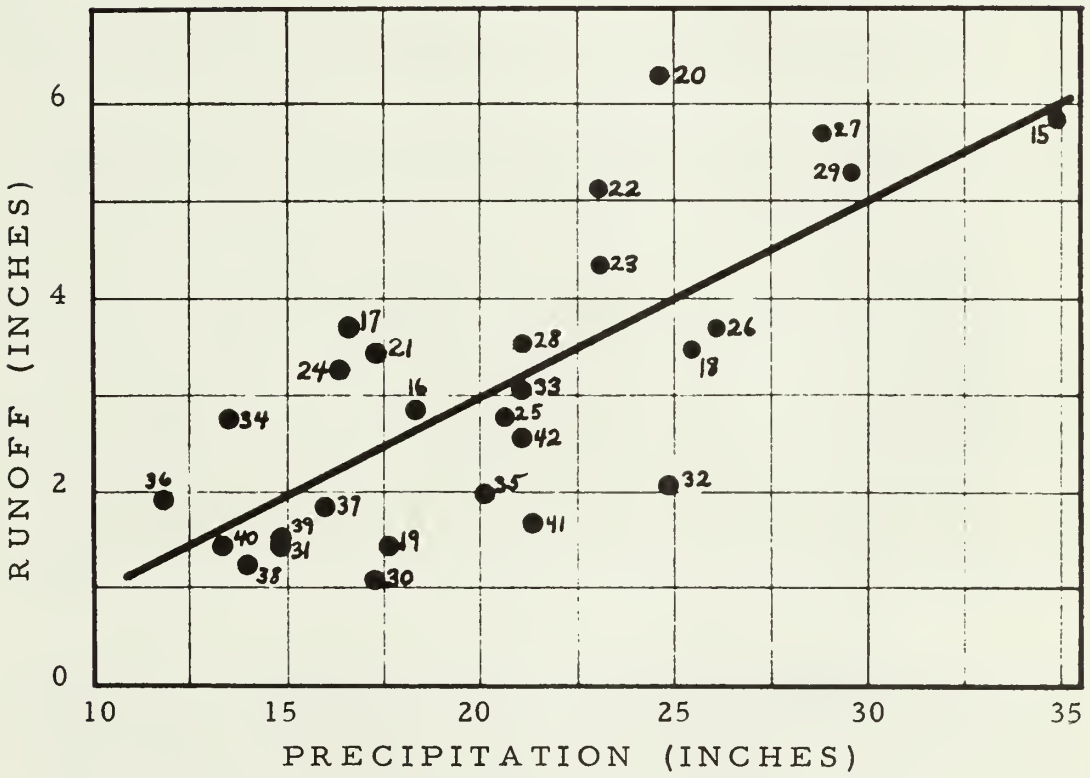

Figure 10. --The net relationship of yearly runoff 1915-42 from Rapid Creek at Big Bend to yearly precipitation holding antecedent fall precipitation at its mean or average for the 28-year period. The numbers by the dots indicate the year of record.

The combined relationship of annual precipitation and antecedent precipitation to annual runoff is expressed by the equation:

$$\hat{Y} = 0.2042 X_1 + 0.5545 X_2 - 3.3360$$

where $\hat{Y}$ = estimated runoff in inches

X_1 = annual precipitation in inches

X_2 = antecedent September-December precipitation in inches

This equation was used to estimate runoff for each year of record (1915-42). Estimated runoff was then subtracted from actual runoff, leaving the residual runoff not accounted for by the precipitation factors. These residuals plotted against year are shown in figure 11. The best fit straight line shows that after removing the effects of variation in precipitation factors there was a significant decline in runoff between 1915 and 1942. According to the analysis the odds are only 1 in 20 that this trend could be due to chance alone.

Unfortunately, the trend cannot be brought up to date. The Big Bend gaging station was abandoned in 1943. The stream was gaged a short distance upstream near Pactola beginning in 1946 and continuing until Pactola Dam was completed in 1956. Since then the stream has been measured at a new location above Pactola near Silver City. Aside from the record lapse and moving the gaging station, the recent record is complicated by waterflow regulation from Deerfield Reservoir upstream and more recently from Pactola Reservoir.

Reasons for the downward trend in runoff, if it is real, cannot be precisely pinpointed, but there are several possible explanations. It may be that some long-term carryover effect or cycle of low precipitation is still influencing ground water storage. Or it may be that more moisture is held on agricultural land by changed tillage and cropping practices and lost to evaporation and transpiration. Another possibility is the change from mature, old-growth, virgin ponderosa pine forest to a more dense second-growth forest that may draw more heavily on available moisture. Improved fire protection and reduction of burned-over area may also mean that more acres are occupied by vegetation, primarily ponderosa pine, and a greater total amount of moisture is utilized.

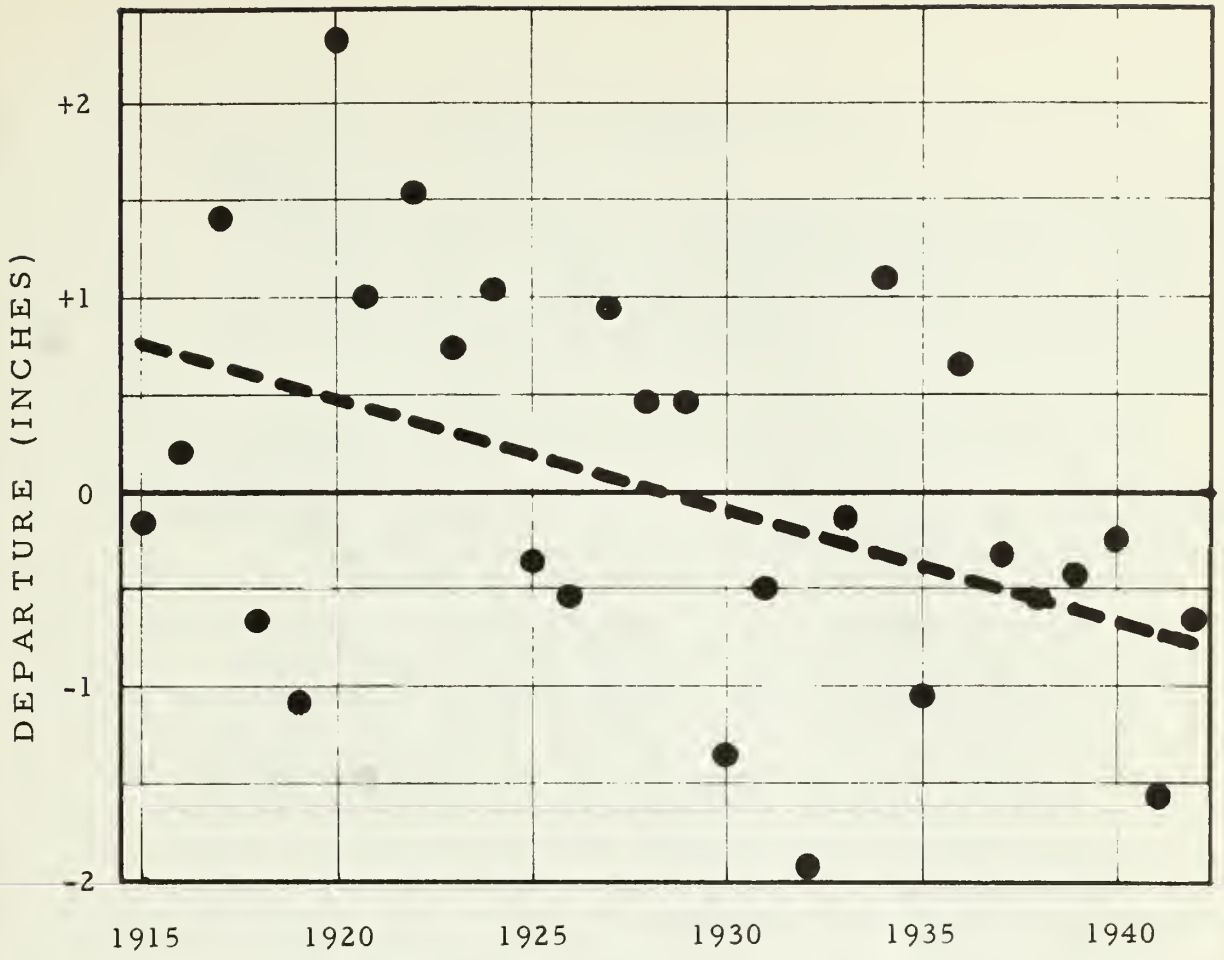

Figure 11. --Departures of actual from estimated yearly runoff in Rapid Creek for the period 1915-42.

SUMMARY

Annual precipitation in the Black Hills ranges from about 18 to 28 inches. Heaviest precipitation falls in the spring and early summer months. From 57 to 69 percent of annual precipitation falls during the growing season, which extends from about the middle of May to near the end of September.

Yearly runoff averages 3.06 inches or 14 percent of the 21.46 inches of yearly precipitation in the Rapid Creek watershed located near the center of the Black Hills area. Water yield apparently is greatest in the northern Black Hills, which receives more precipitation than any other part of the area. Numerous perennial streams head in northern parts of the Black Hills in contrast with intermittent flow in streams heading in southern and southwestern parts.

Water-yield differences between the northern and southern Black Hills are also believed partly due to differences in evaporation stress and moisture demands by vegetation. Both of these factors increase with air temperature, and air temperatures are higher during the growing season in the southern than in the northern Black Hills. This creates a greater demand upon available soil moisture and helps account for the characteristic intermittent streamflow in the southern Black Hills.

Well-distributed precipitation throughout the summer favors plant growth. At the same time, this precipitation occurs when temperatures are high and plants are drawing heavily on moisture, which means that less water is available for streamflow.

There was, according to statistical analysis, a definite trend toward less runoff per unit of precipitation in the Rapid Creek drainage between 1915 and 1942. Rapid Creek is the only stream in the Black Hills with a record long enough for such an analysis. The gaging station at which these records were collected was closed in 1943. Therefore, it is impossible to determine whether the downward runoff trend continued. Nor is the downward trend in runoff from Rapid Creek necessarily an indication of a similar trend in other Black Hills drainages.

Reasons for the trend toward less runoff per unit of precipitation cannot be precisely pinpointed. It could have been due to any one of several factors or to a combination of factors. It could be caused by changed cropping and tillage techniques on agricultural lands, a long-term carryover effect of deficient ground water storage, or the gradual transformation of old-growth virgin ponderosa pine to more dense second-growth stands.

This report is based on existing records of precipitation collected mostly by the U. S. Weather Bureau and cooperators, and existing records of streamflow gathered mostly by the U. S. Geological Survey. The records are all useful for some purposes but analyses showed much of the data inadequate for establishing precise water-yield characteristics or precipitation-streamflow relationships. There is a definite need for additional carefully located and operated precipitation and streamflow gages to establish hydrologic characteristics more precisely and to inventory the water resource.

LITERATURE CITED

1. Brown, Carl B.
   1944. Report on an investigation of water losses in streams flowing east out of the Black Hills, South Dakota. U. S. Soil Conserv. Serv., Spec. Rpt. 8, 45 pp., illus. [Processed.]

2. Foster, Edgar E.
   1948. Rainfall and runoff. 487 pp., illus. New York.

3. Goodell, Bertram C.
   1958. A preliminary report on the first year's effects of timber harvesting on water yield from a Colorado watershed. U. S. Forest Serv., Rocky Mountain Forest and Range Expt. Sta. Sta. Paper 36, 12 pp., illus. [Processed.]

4. Johnson, Harley N.
   1949. A climatological review of the Black Hills. Black Hills Engin. 20(1): 3-35, illus.

5. Johnstone, Don, and Cross, William P.
   1949. Elements of applied hydrology. 276 pp., illus. New York.

6. Matthai, H. F.
   1956. Index of surface-water records to September 30, 1955. Part 6. Missouri River Basin. U. S. Geol. Survey Cir. 386, 44 pp.

7. Thornthwaite, C. W.
   1948. An approach toward a rational classification of climate. Geog. Rev. 38: 55-94, illus.

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